



BUILDINGS AS SYSTEMS  
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by

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Ir.Ars. Institut Teknologi Bandung , INDONESIA, 1959.

SUBMITTED IN PARTIAL FULFILLMENT OF  
THE REQUIREMENTS FOR THE  
DEGREE OF MASTER OF ARCHITECTURE

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 1965

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Cambridge 39, Massachusetts

June 25, 1965

Dean Pietro Belluschi

School of Architecture and Planning


Massachusetts Institute of Technology

77 Massachusetts Avenue

Cambridge 39, Massachusetts.

Dear Dean Belluschi:

In partial fulfillment of the requirements for the degree of  
Master of Architecture, we hereby submit these projects entitled  
" Buildings as Systems"

  
\_\_\_\_\_  
Herman Soetrisno

## ACKNOWLEDGEMENTS

The author wish to thank the following whose assistance and advice contributed substantially to the included thesis projects.

1. Professor Wacław Zalewsky , Poland.
2. Members of the MIT Faculty who participated in the preliminary thesis jury , May 1965.
3. Professor Eduardo F.Catalano, Thesis Advisor.

## ABSTRACT OF THESIS

The objective of the following thesis report was to study the design of a prototype building of about 600.000 square feet gross floor area as an integrated system of space, structure and services, to be used for the development of scientific and technological ideas for furthering the exploration of space.

The general building program was first analyzed and the buildings constants determined. The emphasis was then on studying integration of the building's structural and mechanical components into an all encompassing system for this particular building type.

Precast and prestressed concrete were chosen as construction materials to be studied for their design procedures and proper usage.

This report is an efforts and approach to the solution of research and development buildings as a system. It contains : the author's objectives, the program to which he designed and an explanation of his proposal in that order.

The proposal by this author is for a building system with an emphasis on providing ease of expansion of the total building as well as maximum interior space changeability.

The introduction to these thesis report covers the common research done by the author in preparation of his approach and is a summary and views on the development of systems in buildings the path that architecture will follow in the future.

This work was done under Professor Eduardo F. Catalano of the Department of Architecture and Professor. W. Zalewsky from Poland, as instructor in the building or structural engineering.

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## BUILDING AS SYSTEMS

### INTRODUCTION.

The words system, organism, scheme, network, complex , come into comparison when they mean an organized integrated whole made up of diverse but interrelated and interdependent parts of elements. Elements which participate in the performance of a given function.

System applies both to a natural and to an artificial aggregation all of whose units operate or move in unison obidience to some form of control so as to form a distinctive and coherent whole.

Looking in the nature you will find everywhere systems. A system of organism, a system of systems that have actual life. In other words life has always something to do with systems.

What about architecture? It is said that architecture is a true mirror of the life. So, architecture should have something to do with systems too.

There is no building that is built without any components. And these components is put together as an organized articulated whole. The more modern the building, the more number of kinds of components you need, the more complex the solution will be. And systematizing in every approach becomes more and more important.

While architecture is said to be also a true mirror of the social behaviour of a period, it will not escape from the driving forces of our time. What are these forces?

Science, technology and industry seem to be the three major forces in this twentieth century, which force people to move from one period to another era, bringing benefit as well as confusion to mankind. And once more, systematizing should be the answer to prevent this confusion.

" Perfection of means and confusion of aims seem to be characteristic of our age " (Einstein)

Science allows daring constructions and structures. Technology invents and improved qualities of new building - materials, equipment and tools. In every area of activity technology and science have induced new attitudes. The comprehensive idea of technology gradually arose and began to replace that of the craftman.

Industry, as a consequence of the invention of the machine, enabled us to produce component of buildings in mass production, because the machine has the ability to turn out products of uniform peak quality

Industrialization now is a fact, which can no longer be explained away, which had a direct or indirect influence on every activity, every functions and every objects.

The handtool developed into the machine and the machine became the tool of the times. Prefabrication and standardization naturally become involved in this procedure. Uniform standards which dimensionally develop from systems of modular coordination.



The new philosophy in architecture recognize the pre-dominance of human and social requirements and it accepts the machine as the modern vehicle of form, to fulfill their very requirements.

" The century of the machine awakened the architect. New tasks and new possibilities produced him. He is at work now everywhere" (Le Corbusier)

After realizing the role of these three forces is it any wonder that the architectural needs of our culture are characterized by dimensions and number ? And that systematizing is the best - if not the only - way to achieve the most satisfactorily results ?

With systems we can gain highly functionally and structurally justified buildings, as the consequences of our purely analytical and intellectual approach, and yet without loosing another important principle : life. Because buildings have to express life and allow life to develop.

This is a challenging problem in modern architecture to make use of repetative standard parts, but at the same time to organize these parts in groups which can vary in appearance, to break the monotony.

While mass production becomes more and more common because of industrialization, structures become more and more daring, functional. The change of attitude and need of the modern man has also a great influence in the development of modern architecture. Science and technology increase the selfconfidence and eliminate the "horror-vacui" feelings, with as result the change in the scale of life.

They move to wider areas, they think also in wider and larger scales. Coinciding with this urge to wider worlds, increasing importance of economic factors and also population explosions increase the density in bigger cities to result in a bigger need for larger structures. Large apartment buildings, large stations, large theatres, all these appear in increasing numbers. The large structure has become a symbol of our culture.

What will be the path that architecture will follow in the future ?

In his book : "The Turning Point of Building" , Konrad Wachsmann points out the following items :

- Architecture will follow the concept of simplicity.  
However, when something is very simple, a product of necessity, then it is also perfect and therefore identical with the concept of beauty.
- The idea of a building as a solid structural mass will gradually give way to the idea of combinations of functions and individual elements.
- The design will be dominated by vertical and horizontal stratification of surfaces, conceived as planes of movements ; at the same time these surfaces will establish the porous character of the building mass, enclosed by functional elements rather than solid walls.
- All planning is primarily influenced by free space. Larger spans mean that space will be conceived in unprecedented ways. In these wide-span structures the systems of supports may sometimes be secundair. Moreover, their structural purpose will not always

- be apparent as ties, panels and open space systems will act as load transmitting elements.
- The starting points for structural conceptions must be the cell or unit element.
- Technological perfection is the prerequisite, but the goal remains the wresting of knowledge and the art of building.

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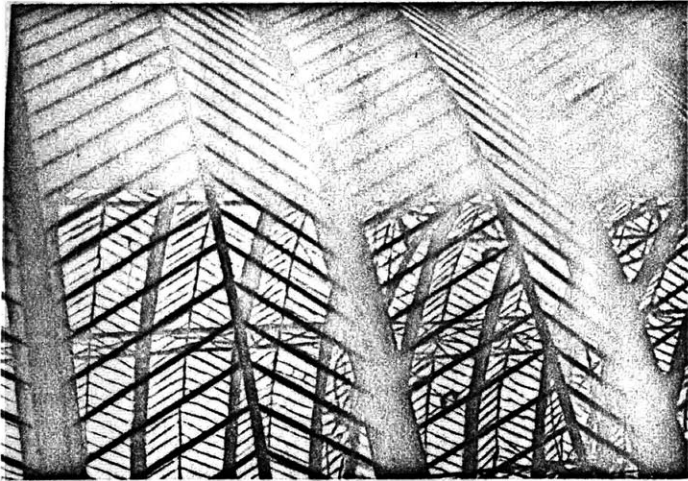
There is another aspect is future construction : it will have to be designed not only to be multidimensional but multifunctional .

In the future more conscious attention will be paid to the multi function of structure as a mechanism, or as an integral part of a mechanism, of environmental control ; we shall design new heat, light and sound conditions as well as support or space division.

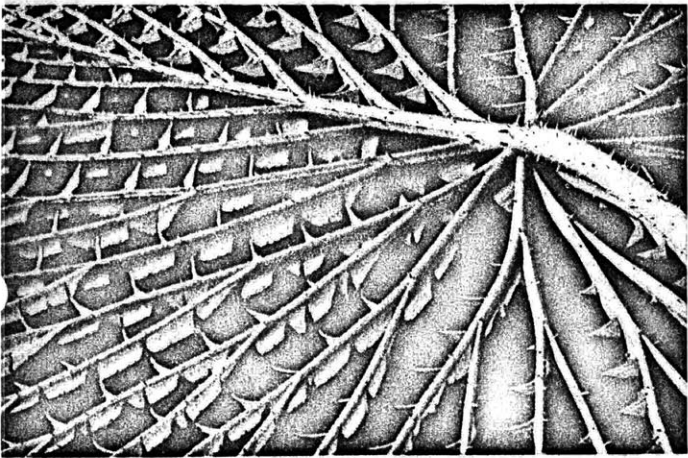
At present we achieve multifunctional characteristics largely through auxiliary structures such as hung ceilings. The single grid can care for high-class illumination, acoustic control, sprinkling, air-conditioning outlets and attachments for removable partitions.

We can hide the mechanics visually without putting a continuous membrane under them.

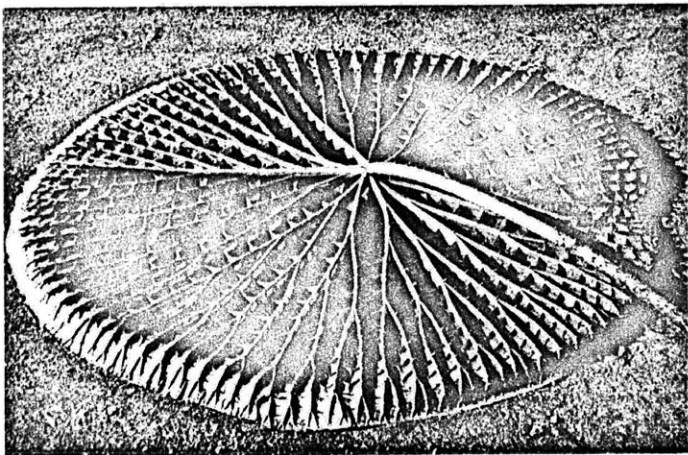
Summerizing, we come into the conclusion that tomorrow's structure will be a more complicated problem. It will be designed to more dimensions than now; it will be called on to perform more functions simultaneously and will serve a more varied architecture; it will need and get many new materials coupled with new methods of construction and accordingly entail more difficult analyses.



**13** View through the ridge-and-furrow system of glazed ribs forming the barrel vaulting of the main hall and transept of the Crystal Palace

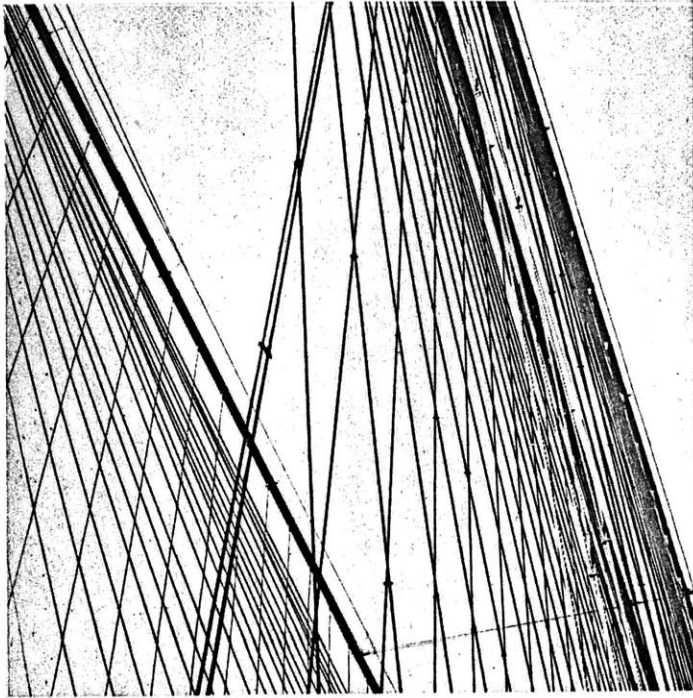


**14** Paxton says that in his youth, when his main preoccupation was gardening, he got the idea for his later building projects from a study of the leaf of the Victoria regia

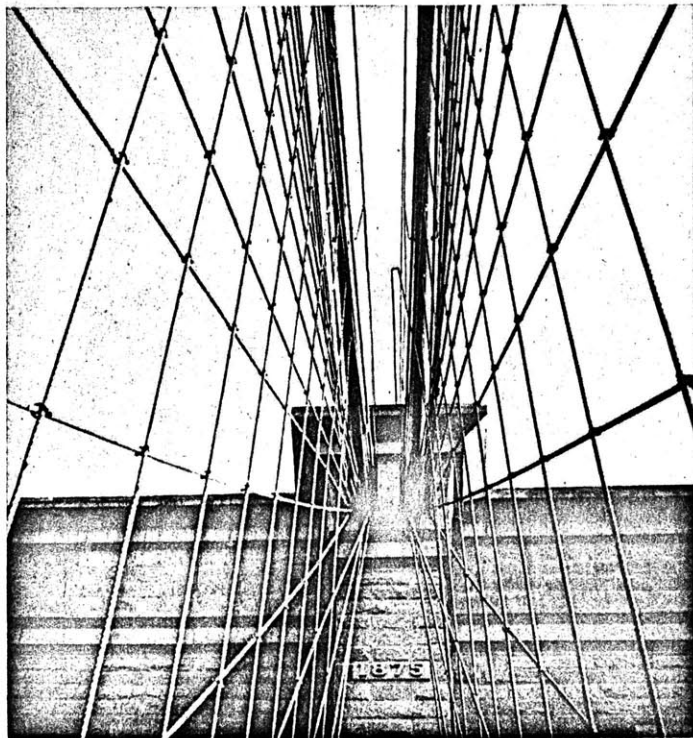


**15** At Chatsworth in 1837 he began building what was then the greatest conservatory in the world, to shelter the Victoria regia; the structure of the leaf of this plant is shown here

**16** Roof of the Crystal Palace in London, designed by Sir Joseph Paxton in 1851; view looking towards the transept. On the left, below the line of the glass vaults, are the continuous, bent-sheet louvers. The originally completely standardized flat sections of the ridge-and-furrow glass roofs were partly modified in the course of subsequent remodeling

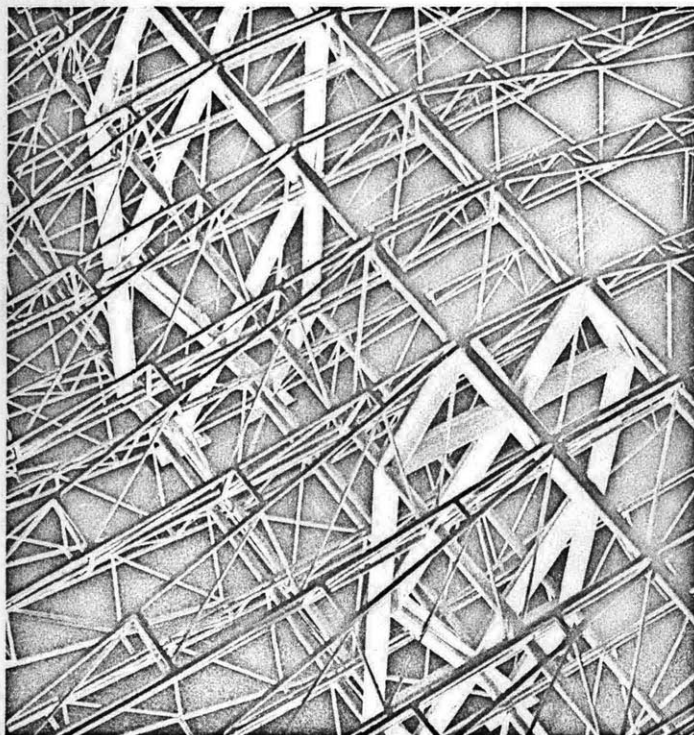


**36** The suspension system of the Brooklyn Bridge, a network of intersecting cables

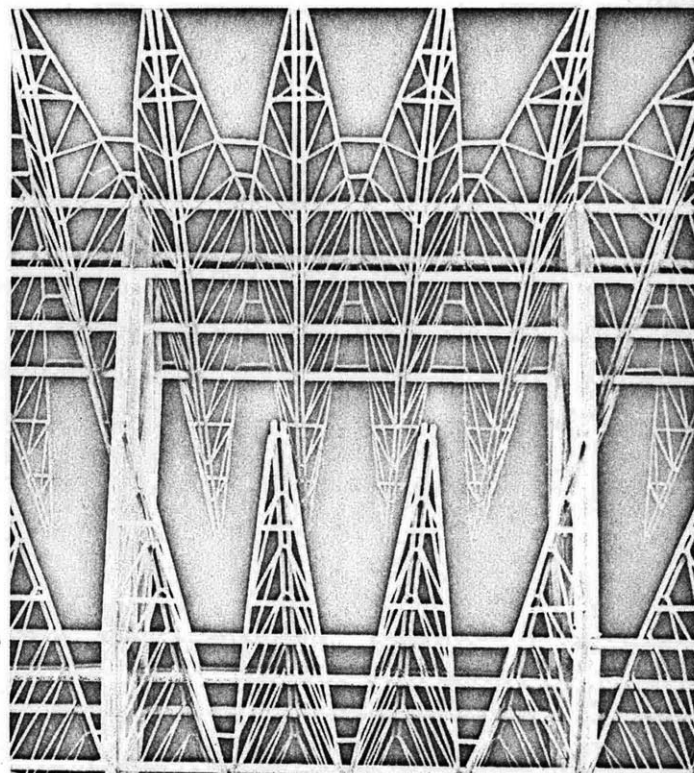


**37** From the frozen blandness of the masonry pier springs an airy, linear structural system, which in its vigor triumphs over the massive stone pile

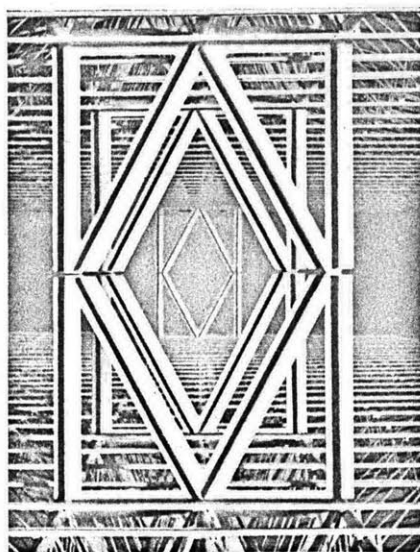
**38** Abstract effects achieved by linear systems of material elements defining a space previously unimagined ▶



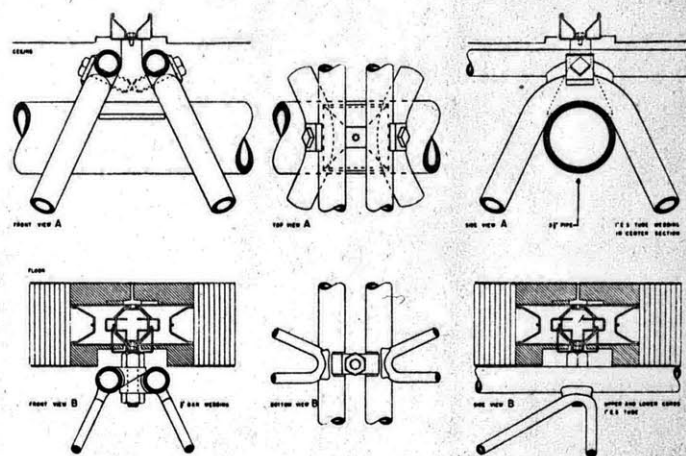
324 Close-up view of the structural system



326 Saw-toothed arrangement of simple aluminum trusses, linked by horizontal cross members to form a space frame system



325 Column system, based on a symmetrical, triangular arrangement and connected at floor and ceiling



327 The standard connection between tubular structural elements and its relationship to the building panels, a detail developed in an earlier team project



## OBJECTIVES:

The objective of this thesis report is :

to study the design of a prototype building to be used for the development of scientific and technological ideas for furthering the exploration of space, with a solution that provides:

- an integrated system of space, structure and services.
- possibilities of future expansion or growth.
- greater flexibility in the use and arrangements of internal spaces, both horizontally and vertically.

## PROGRAM :

The range of kinds of research that is done in modern laboratories is so wide that for this particular building study the program will be limited generally to fields that don't need facilities housing chemicals, pharmaceutical and medical research. Within this general category there are the following groups of requirements:

1. Spaces with general office requirements.
2. Spaces with typical laboratories requirements.
3. Spaces with ancillary functions.
4. Spaces for general services.

1. Spaces with general office requirements:

To this group belong primarily the administrative offices, pure and theoretical laboratories with spaces ranging from minimum 100 square feet to 400 square feet in size. There is however a need of larger areas for secretarial and clerical sections either open or semi-divided into smaller cubicals.

These spaces need a minimum room height of 8 feet and is usually located as near as possible to the windows.

Their physical needs include air-conditioning, mechanical and electrical services, such as telephones, light and power.

2. Spaces with typical laboratories requirements :

The second group has a very wide range of variety of needs. There are spaces ranging in size from 70 square feet for instruments rooms up to 7500 square feet working spaces.

The height of the room varies according to the needs of the particular work being done.

Mechanical and electrical services to be provided to these areas must be sufficient, with always the possibilities of adding additional service.

3. Spaces with ancillary functions :

These could include auditorium, lounges, restaurant, restrooms, public receptions, workshops, and conference rooms.

Height and size varied according to the different use and requirements. Their needs are primarily air-conditioning and electricity.



#### 4. Spaces for general services.

There are horizontal and vertical services, both include mechanical as well as electrical. To be included in this category is also the cores that contains of elevators, stairs, toilets and shafts.

The way these groups of spaces are located in relation to each other is generally as follows:

In general, staff members prefer to have offices separate from, though somewhat near, their research laboratories. Frequently these offices adjoin the laboratories. The separation is desired in part because of noise. Offices are usually grouped together either in one or several areas of the building. This makes it possible for members of the staff with similar problems and interest to confer more readily with each other. Most persons want windows in their offices. They like to be able to look outdoors, possibly simple to rest their eyes. But interior offices can be acceptable if it is well lighted and adequately ventilated.

The ancillary and the administrative groups should be located centrally because of the common use. Services are located on certain distances serving the whole building equally. The remaining areas are laboratory spaces, divided into physical project groups according to their participation in a particular program. Because one physical project group might include a center of theoretical scientists, with small laboratories near them surrounded by larger laboratories and shops where technicians are assembling apparatus. This would then be the typical composition of such a project group and the whole research building consist of several of these project groups.

Depending on the progress and need of every project group, one group may increase or decrease in physical size. That is why these laboratory area's have a typical character of always changing the need and use.

The location of these spaces depends on a number of factors such as :

- the efficiency with which the required mechanical and electrical services can be supplied.
- floor loading required.
- freedom of vibration
- ease of installing equipment that is either bulky or heavy.
- ease of access to materials and auxiliary services.

Because of floor loading requirements and the difficulties of transporting heavy equipments to upperfloors, research requiring such equipment is usually confined to the basement or sub-basement where the concrete is poured directly on the earth. The groundfloor is also best for experiments which require freedom from vibration.

#### APPROACH:

It is not unusual that the development of a research project is hampered only because of the lack of space. Expansion of building needs time and money. And in the meantime the research project has to be slowed down. And if there is an expansion, it occurs in a way that in the first coming periods, a lots of spaces will not be used very efficiently because of the abundant expansion.

The following studies is made to solve this problem and to get into a solution that satisfied the three important requirements:

- 1.- flexibility and efficiency in use
- 2.- flexibility and efficiency in structure
- 3.- flexibility and efficiency in expansion.

#### A) Site plan :

It is preferred to be on a open rural hill site with space for horizontal expansion.

The plan should be a complex of buildings that eventually can grow also into one unity. The plan could start with one building and gradually grows to two and more buildings, depending on the need.

As focal point of the complex, and also as center of life activity, a court with landscaping goes through the center of the site deviding the site into two parts. This court is freed from every vehicle traffic, and is only used for pedestrians, while the two parts on the flanks are used for parking area's. Libraries, restaurants, auditoriums will be located in this centre court. Also other common activities like main entrance, main lobby, main staircase are located in this area. This space has a different level than the parking area.

Parking facilities are mostly on the ground level below the buildings. Entrances for pedestrians, cars and services should be seperated from each other.

#### B) The Building(s)

When space permits, one- and two story buildings seem to offer more possibilities for expansion than higher rise buildings. This advantage, as so many in architecture, has been first recognized in industrial buildings.

The multi-story scheme is typical of most research and science buildings. Besides requiring less site area than a single story structure, a multy story building requires

less outside surface for a given volume. An additional advantage includes the greater efficiency in layout of electrical and mechanical services possible in a multistory structure. Where toilet room fixtures, sinks, services, outlets and drains occur repetatively, there are advantages in stacking them one above other. Shorter duct and pipe runs are required. Besides reduction of initial cost, shorter runs result in less frictional loss for fluids and less voltage drop in the case of electrical runs.

This prototype building will have 5 stories as a maximum.

### C) The Structure.

The building is composed of structural units that have the ability to be added to each other, or eventually subtracted from each other. It should have great flexibility in growth horizontally as well as vertically.

It is decided to use a one way system. Not because of the result of studies concerning the advantages and disadvantages of this system compared with the other structural systems. But to explore the possibilities in fullfilling the requirements of flexibility, growth and efficiency.

The use of precast, prestressed concrete is preferred, because of the many advantages over other structural materials. It provides both structure and finished surface and is fireproof. It lends itself with the use of prestress to long spans and it can easily be formed with high degree of precision and economy by used of repetative forms under controlled conditions.

To fullfill the requirements, this unit has to be selfsufficient with respect of the mechanical and electrical systems.

## DESCRIPTION :

### A). The building.

The buildings have different height with a maximum height of five floors, not including the basement. It can be built in several stages, vertically as well as horizontally with on the final stage reaching the total floor area of 600.000 square feet. 10 % of the total area will be used as mechanical rooms, which mean then 50 % of the basement.

The first stage can be started with one multicore, serving a 5 story building with a total floor area of 120.000 square feet. The following stages can occur on the same way, but also partially, according to the direct need. With partial growth this author means by adding one or more structural units to the existing building, on every side and direction.

In order to give the people inside the buildings a clear orientation, cores are located in a certain rhythmical pattern.

The exterior of the buildings is covered with curtain walls, consisting of concrete prefabricated components, or glass-windows, following the five feet grid. This module is chosen to best accommodate present furniture and equipment size.

The interior can be divided by moveable partitions following also the 5' grid. The height of the ceilings are 10' for the working spaces and 8' for the core.

Depending on the use and need, certain areas of floors can be removed, so that you get different height of ceilings, or you get another court.

### B) The Structure.

The basic structural unit has a bay of 40' x 60' and is a one way system, with girders on the short side and beams on the longer side. This unit is composed of : columns, girders and T-beams.

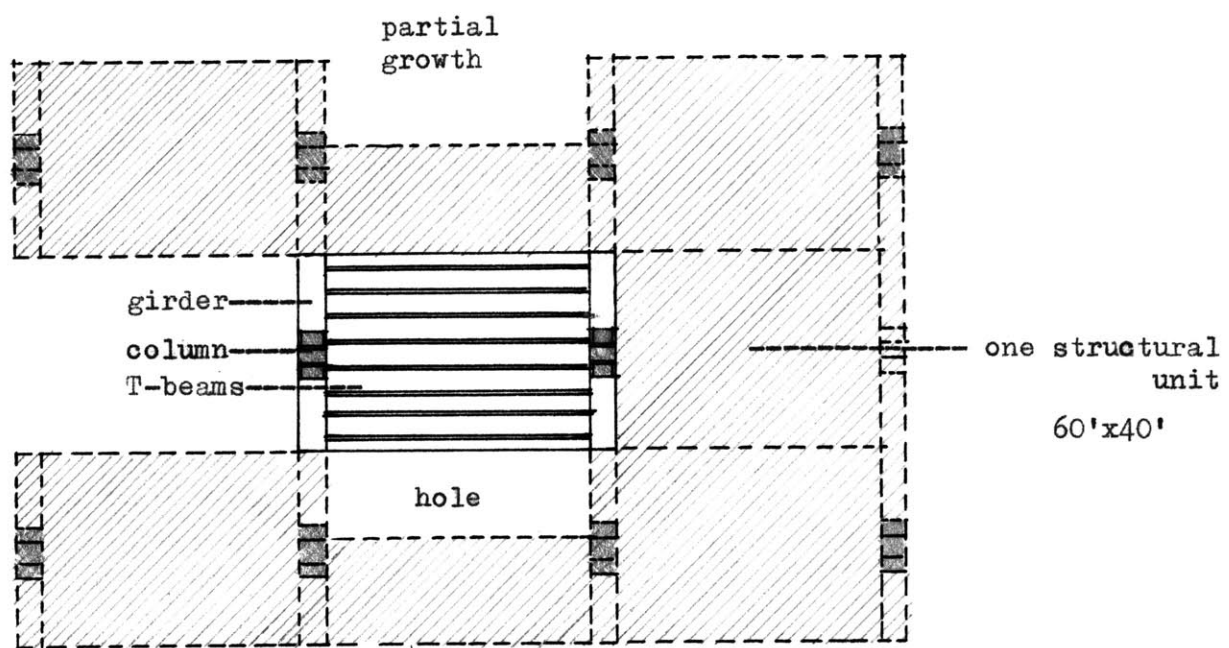


Fig. I. GROWTH POSSIBILITIES OF A STRUCTURAL UNIT.

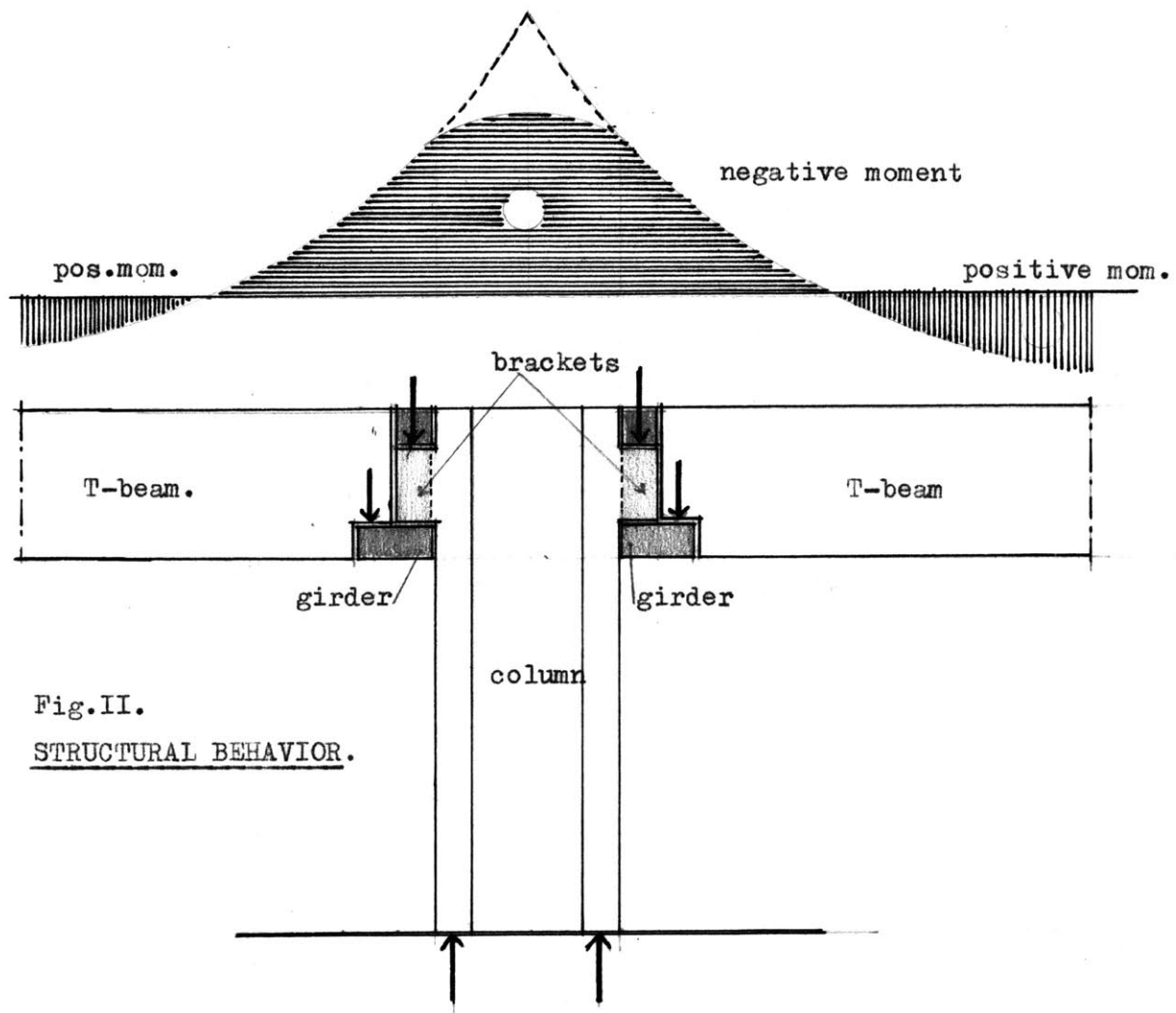
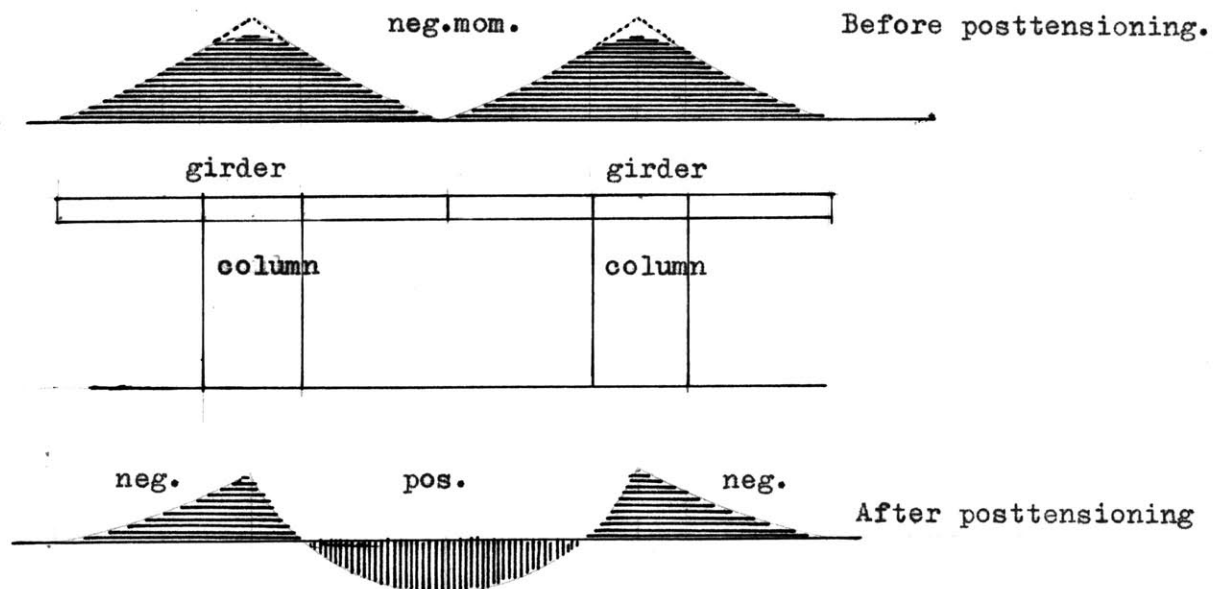


Fig.II.  
STRUCTURAL BEHAVIOR.



Column:

The column has not only the function of supporting, but also of supplying, because air supply-and-return ducts, waterpipes, sewages and other utilities are stored in it. The maximum volume of utilities that has to be stored in the column determine the size of the column.

Each column contains of two separated parts, each of it with an U-shape. This shape will give the column more lateral stiffness and also prevent it for buckling. It is also the most functional shape considering the function of the column as supplier.

On each side of the column is a shoulder-like bracket to support the girders. This non-centric solution is chosen because of the following advantages:

- a). The girders will not disturb the continuity of the duct flow and other vertical circulation.
- b). During construction, columns can be built up until more than one floor at once.
- c). Keep the column on a minimum size that fit in the 5' grid.

The most unfavourable loading of the column would be the non-symmetrical loading, and that is on the edges of the building, where the columns will be loaded only on one side. With the U-shape and double reinforcement this problem can be solved.

The distance between the two bracket of both parts of the column (7') and the double girders on every side of the column, will increase the stiffness of the whole system.



### Girders:

The girder has a rectangular shape but with a thickening on the lower side, forming a bracket to support the T-beams, and has the size of 1' x 4' and is 40' long. Perforations are made in the girders to let ducts and pipes through, also to lessen the weight. One main hole in the center is for the joints with the columns. The girders are then so to say "hanged" on the columns.

On the upper part of the joint a piece of steel is welded in order to prevent the girders slipping off from the brackets.

These girders form cantilevers on both side of the column. To meet the negative moment on the joints, double steel reinforcing or poststressing is needed on the upper part of the girders, while the lower part needs more concrete in order to meet the compression .

So the thickening of the lower part of the girders has two functions:

- a) to receive load from the T-beams, while supporting them.
- b) to meet the compression because of the negative moment.

This negative moment will be reduced when all of the units become one whole structural system by means of posttensioning.

### T-beams:

T-beams are used to get more efficient structural slab.

These beams are also perforated with the same aim as the girders. In order to be able to integrate the service systems with the structural systems, the height of the T-beams and girders is made the same. Being T-beam is less loaded it is then placed on the longer span, while the girder on the shorter span.

### The Construction:

After the plan is being made, all the columns are put on their foundations and supported by stilts. The joints between two columns, when erected on each other should be welded. Columns can be of variable length depending on the place in the plan. When columns are built at two levels at once, after welding, they should be poststressed.

Girders are hoisted by cranes and put at the brackets on the columns. After posttensioning, the girders will secure the stiffness of the whole structure, to one direction. While stiffness to the other side will be maintained after putting the T-beams on the girders and poststressed.

The space between the two girders is filled with plates. Then finishing can be poured on the plates and T-beams.

After putting the mechanical and other services in the column, a plate of concrete is welded on the sides of the column in order to hide the ducts and pipes.

### C). Cores and Circulation.

Every core is a multicore serving on every level about 30.000 square feet floor area. The size of the core follow exactly that of one structural unit, so that theoretically the core can be built every place desired, by only removing the T-beams of one structural unit.

Every core consist of 3 elevators, 2 fire-staircases, toilets for men and women, shafts, janitor closet, telephone exchange and electrical closets. Where it is necessary, one fire-stair can be replaced with a freight-elevator, without having any structural problems.

The location of the cores is in such a way that the farthest distance from any door to the fire-stairs will be less than 150 feet, except on the ground floor.

D) Mechanical systems.

In order to obtain a large amount of flexibility, every units is served by the columns with their need of ducts and pipes. The location is arranged in such a way that it is always possible to meet unforeseen requirements promptly and economically.

Research laboratories demand extensive electrical and mechanical equipment. This equipment is needed both as experimental and as building equipment to support experiments. Magnet and electronic power supplies, for example not only require heavy electrical current but produce excessive heat which must be removed. Heat removal in turns, requires coolingwater and pumps, refrigerant and compressors and cooling air and fans. Air conditioning to provide temperature and humidity control is essential for much of research. At the same time, the comfortable and more efficient working conditions made possible for personal by air conditioning are becoming accepted as a need rather than luxury.

Mechanical and electrical services are distributed in a building by means of a variety of sizes of ducts, pipes, conduits, bus bars and cables, and they usually share common right of way.

The dimension of the columns and the depth of the girders and T-beams are more determined by the the total amount

of air and other services needed for every unit.

Every 1000 square feet floor area needs 2 square feet of air supply- and return. Every column serves 60'x40'x5 floors = 12,000 square feet. Every column needs a duct space of  $\frac{12,000}{1,000} \times 2 = 24$  square feet. The external dimension of the column is 5'x10' = 50 square feet, being used for structural parts as well as for service ducts.

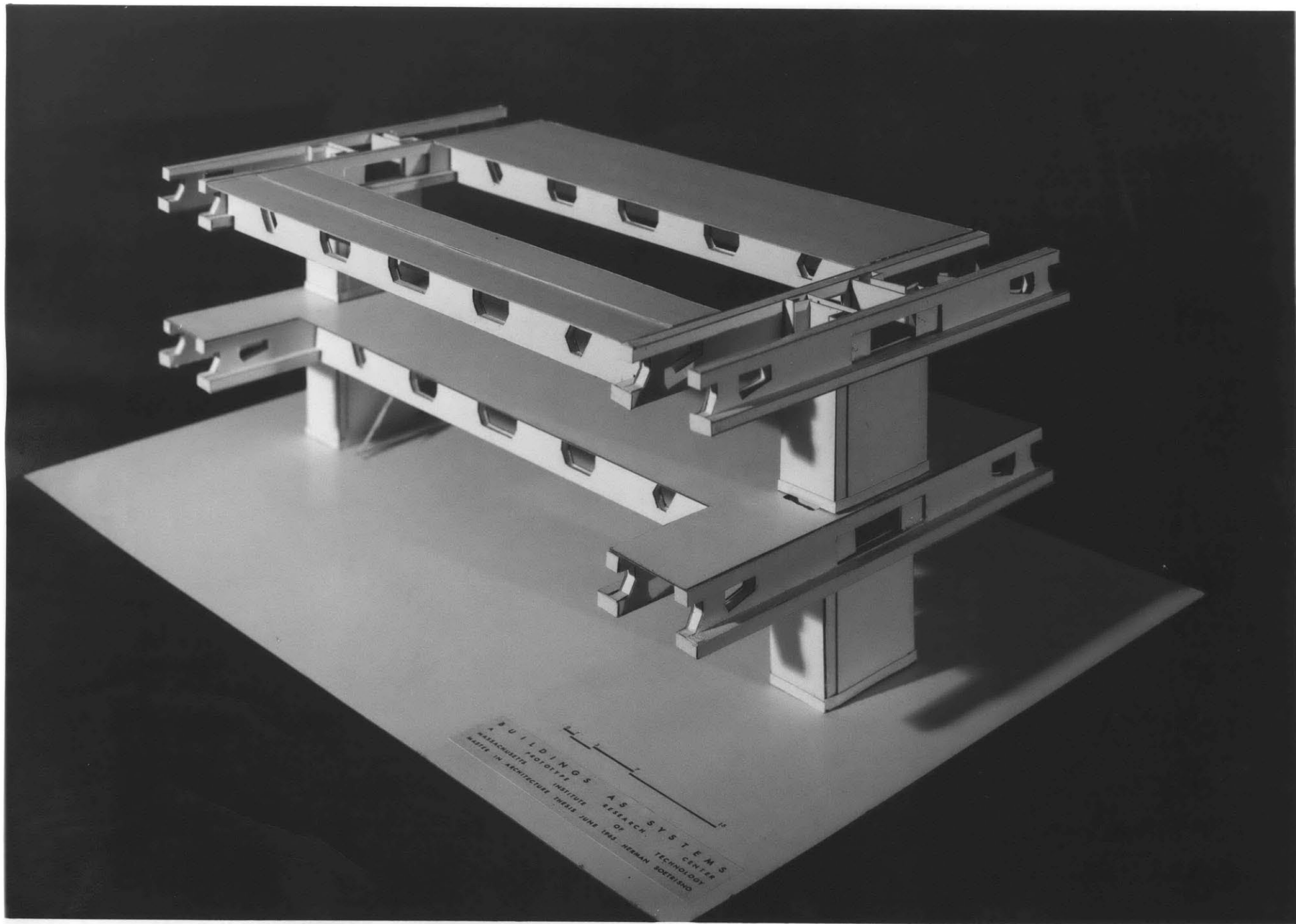
The ducts are distributed in such a way that it can go along the beams, and distributed through the beams without penetrating the girders too often.

Ducts and pipes are very easy to reach for repair.

Because every column has to be feeded, the most effective place for the mechanical rooms is in the basement. Feeding ducts in the basement can go through the ground in the floor to any column without to be exposed too much, and without disturbing any kind of circulation.

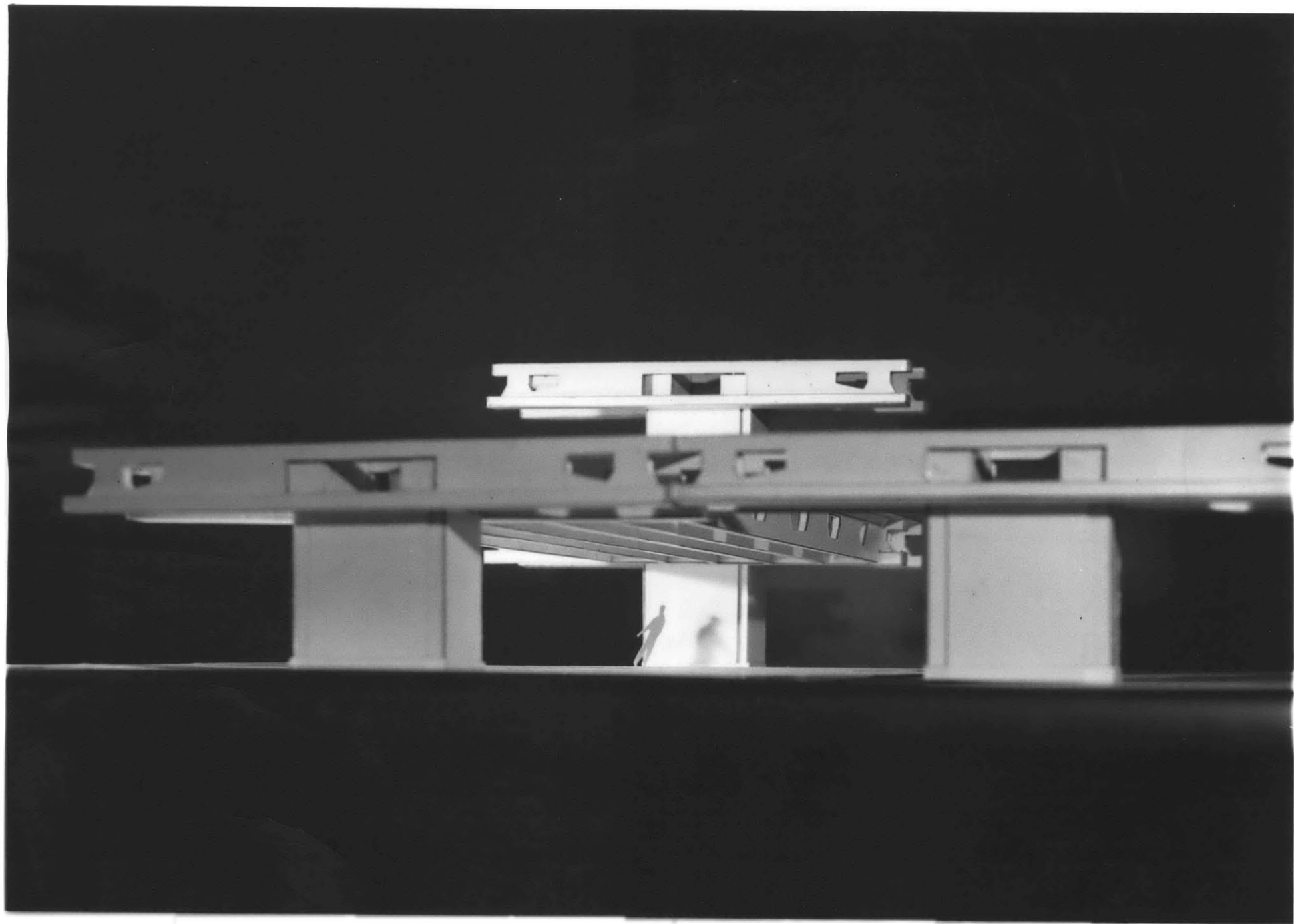
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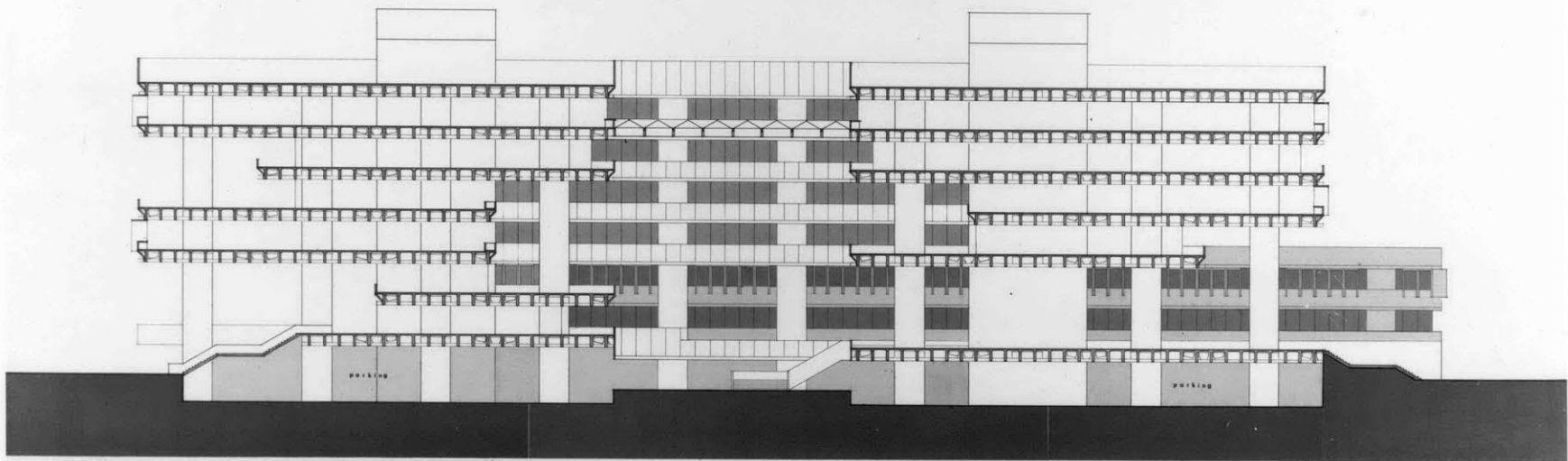
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1" = 1'-0"

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A prototype  
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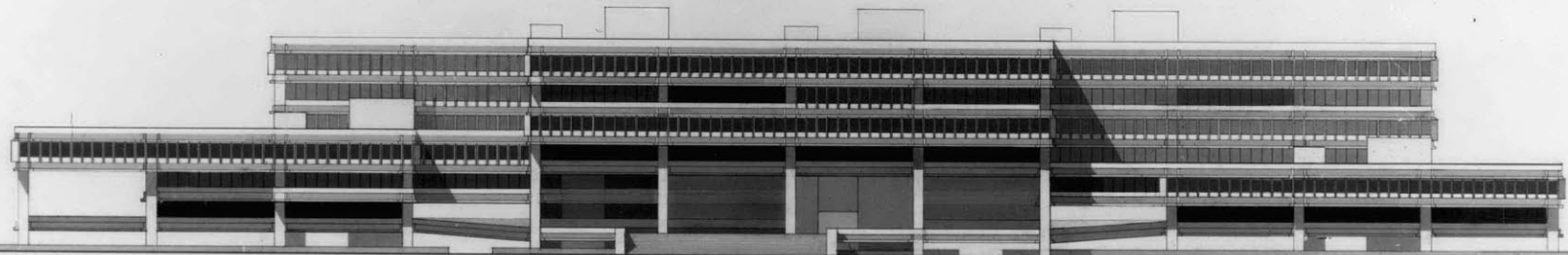
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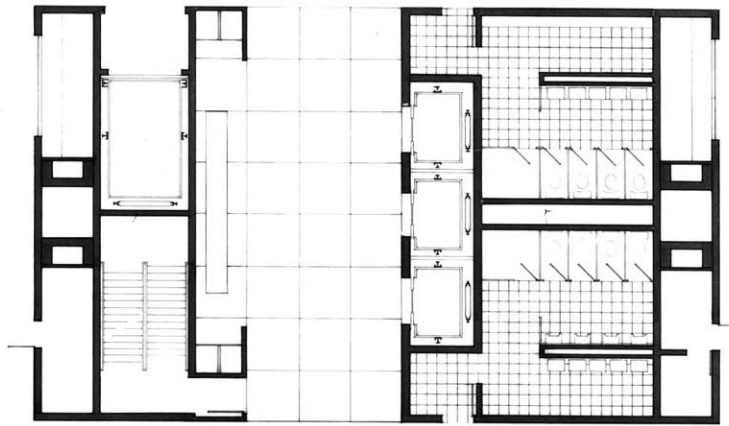
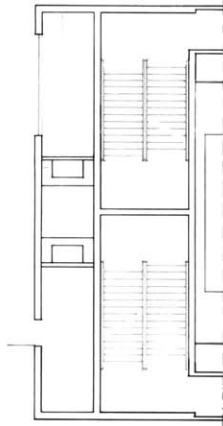
SIDE ELEVATION



FRONT ELEVATION

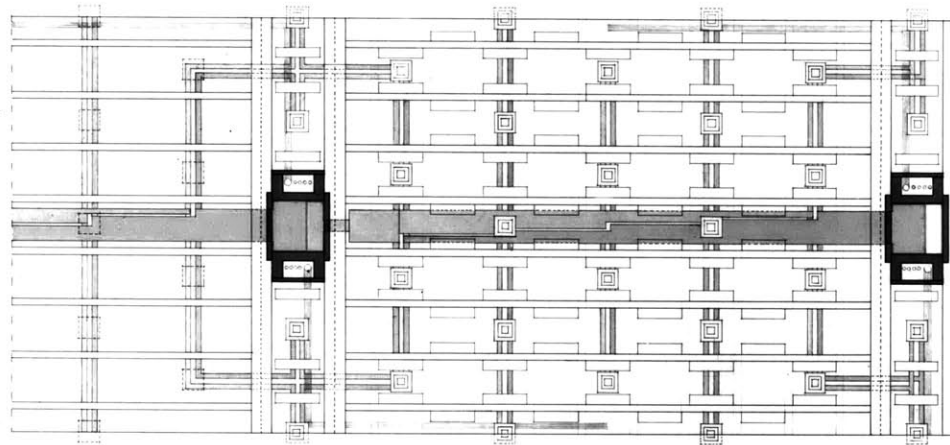
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alternative

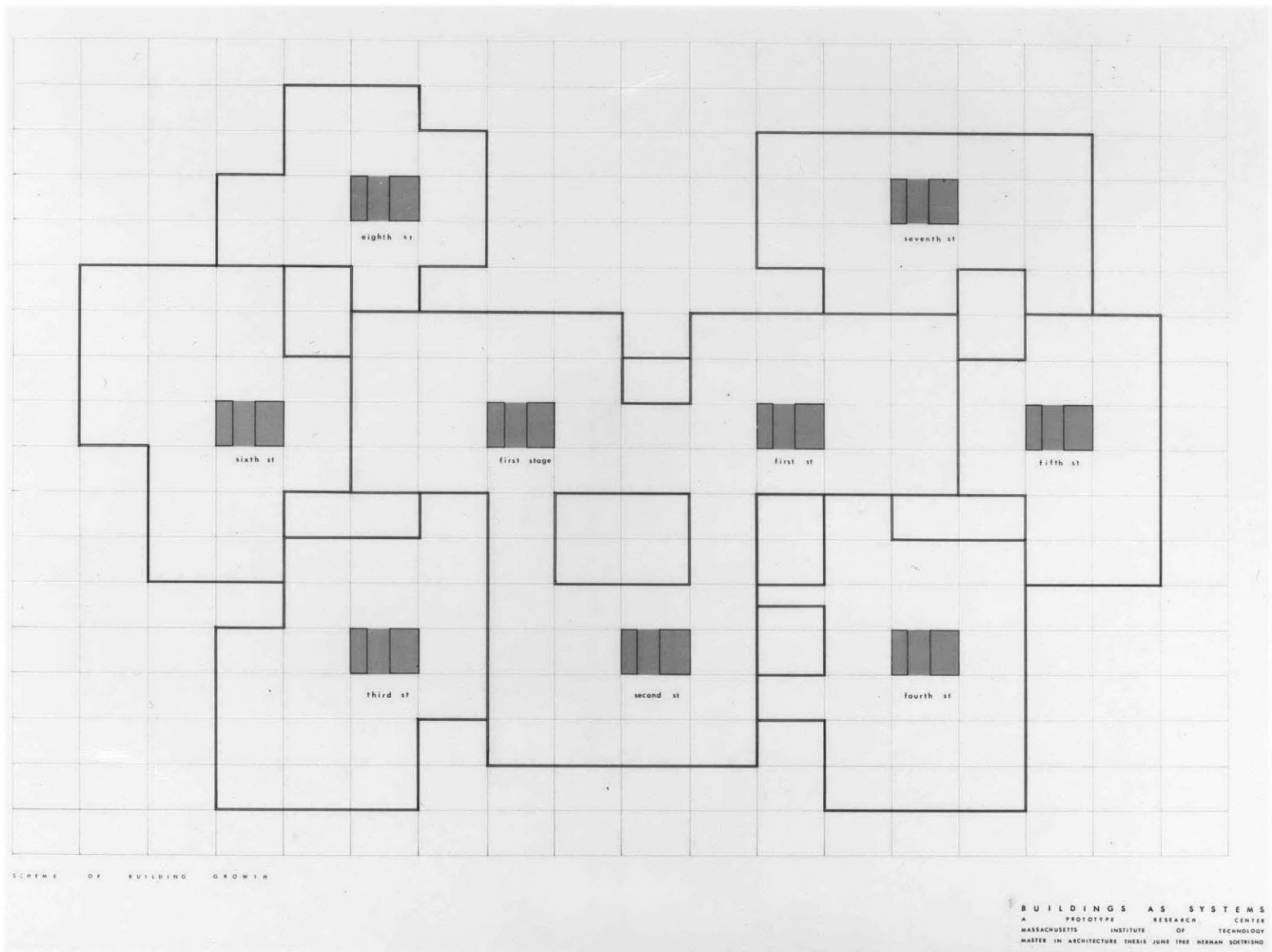


multi core

a.c. system  
plumbing  
lighting

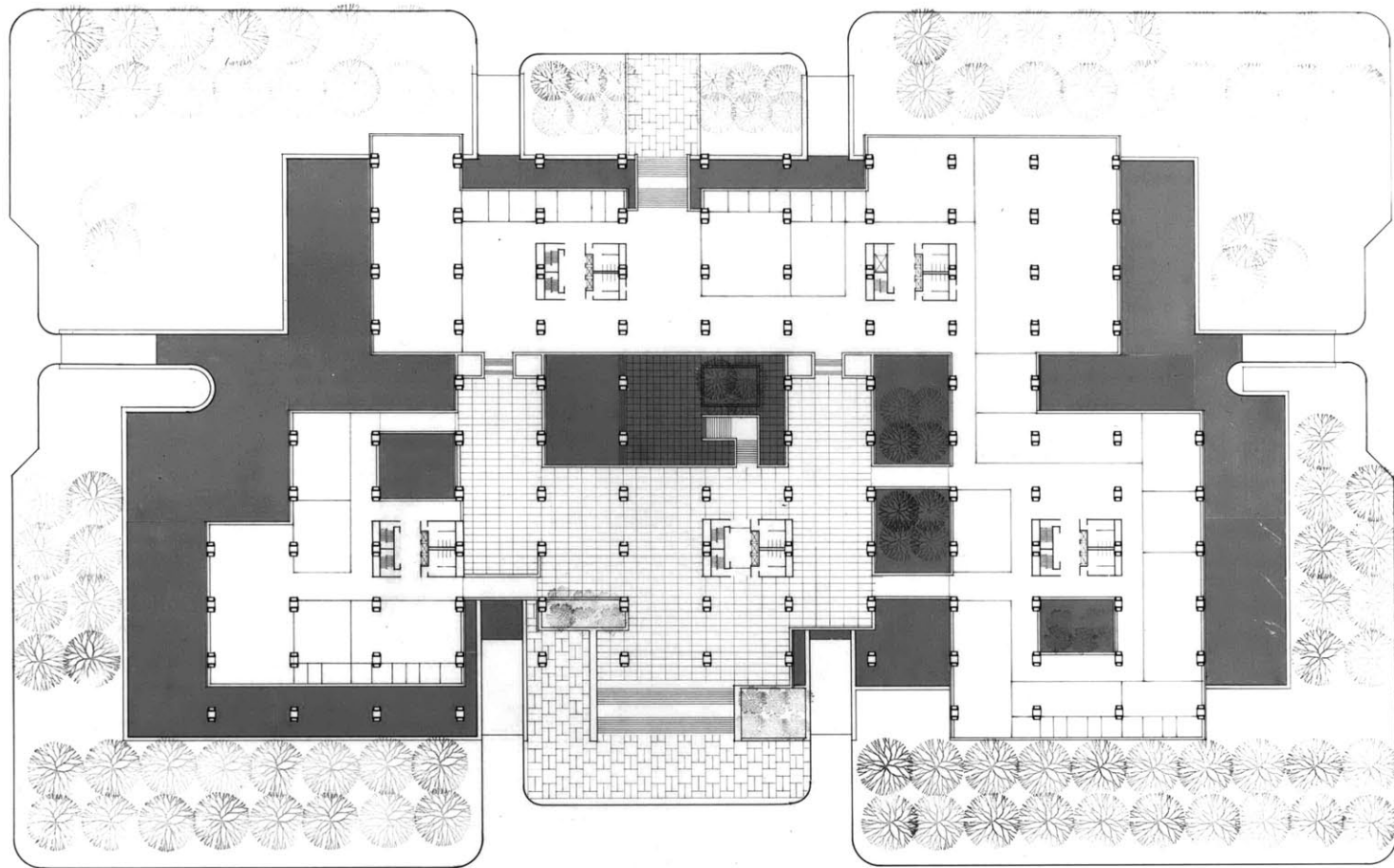


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SCHEME OF BUILDING GROWTH

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